Research on Ship Structural Safety for the Next Century

A.Kumano,T.Shigemi,
Y.Hoshino,K.Ohishi
Research Institute, Nippon Kaiji Kyokai
1-8-3, Ohonodai, Midori-ku, Chiba 267-0056, Japan

1. Background

Ever greater expectations are being placed on the enhancement of the safety of ship structures by the shipbuilding industry, maritime community, and related interests. Within this context, the role which classification societies are expected to play will become increasingly important in the future. In this regard, the rules of a classification society are extremely important as the key tools in achieving these goals. Although the rules of a classification society incorporate the most recent technologies in their coverage, they are also expected, at the same time to reflect the needs of the shipbuilding and maritime communities. Therefore, it is necessary that the basis and background of the rules be clear and that the understanding of all concerned is ensured by making the rules open to the public. In addition, the classification society must always monitor and demonstrate the effectiveness of the rules.

Ships are very complex structures compared with other types of structures. They are subject to a very wide range of loads in the harsh environment of the sea. As a result, it is difficult to prepare rules on the basis of theoretical analysis alone. The majority of actual structural rules of classification societies are based on the results of technical progress backed by many years of accumulated experience. The technical basis and background for the rules are, at present not easily nor readily understood by those outside the past process of rule development. The Society has come to recognize the need to review basic requirements concerning strength, based on current technical knowledge and past experience in order to promote the safety of ships for the 21st century. With the marking of its 100th anniversary last year, the Society sees this as an excellent opportunity to strengthen the technical base of its current and future activities in a proactive manner.

Progress in technologies related to ship design and construction is being made daily, at an unprecedented pace. A notable example is the fact that the efforts of a majority of specialists together with rapid advances in computer and software technology have now made it possible to analyze complex ship structures in a practical manner using structural analysis techniques centering on FEM analysis. The majority of ship designers strive to develop rational and optimal designs based on direct strength analysis methods using the latest technologies in order to realize the various specifications ordered by shipowners to a high level. Moreover, when designs arise for novel structural ship forms, for which there is no prior experience, attempts are also being made to prepare designs through the application of direct strength analysis based on direct load analysis.

When carrying out direct strength analysis in order to verify the equivalence of structural strength with rule requirements, it is necessary for the classification society to clarify the strength that a hull structure should have with respect to each of the various steps taken in the analysis process, from load estimation through to strength evaluation. In addition, in order to make this a practical and effective method of analysis, it is necessary to give careful consideration to more rational and accurate methods of direct strength analysis.

Based on a recognition of this need, extensive research has been conducted into and a careful examination made regarding the strength evaluation of hull structures. The results of this work are being compiled and are reflected in the publication of a *Technical Guide regarding the Strength Evaluation of Hull Structures*. This paper presents a brief overview of some of the main results obtained from this research into design loads for direct strength evaluation.

2. Research into Design Loads for Direct Strength Evaluation Methods

1) Wave Loads

Wave loads are one of the most important loads acting on a ship. The acceptability or quality of analyses of these types of loads greatly influences the effectiveness of the strength analysis of a structure. The wave loads acting on a ship in a marine environment are extremely complex compared with the load conditions to which other types of structures are subjected. Moreover, the fact that a ship is a mobile structure which is operated by man makes load analysis even more difficult when estimating strength.

2) Characteristics of wave loads from the view point of strength

In order to analyze the various types of loads acting upon a ship accurately for strength evaluation, it is necessary to examine the characteristics of the loads acting on a ship under given wave conditions. This includes examining the wave conditions encountered by a ship, the motion response characteristics and structural response characteristics of the ship, as well as the mutual relationship between these loads and the responses of the hull structures to them(see Fig.1).

Loads which works on ship structures in waves alters greately depending on the type, size, forms and structural configuration of the ship. Though various examinations had been made to make a background in the current rules, rule loads are defined based on the length of the ship as design loads regardless of the kind and the structural configuration of the ship and are not necessarily what corresponds to the load acting on ships while actually navigating. Then, the characteristic of loads which work from the viewpoint of structural strength to various ships was investigated about a structural response in waves of the ship. Whole structural FE ship models of Double Hull VLCC, Container Carrier, and Bulk Carrier as typical large-scale ships were made, and characteristics of structural responses in waves were investigated.

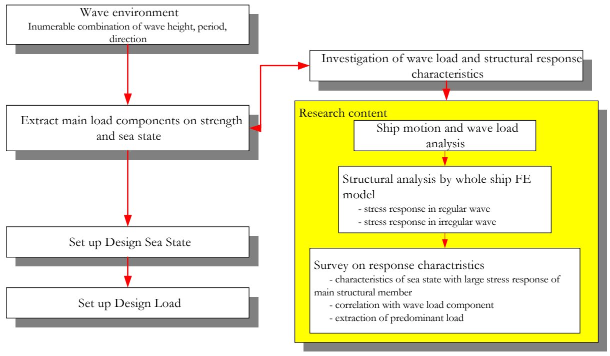

Fig.1 Characteristics of structural response and design loads

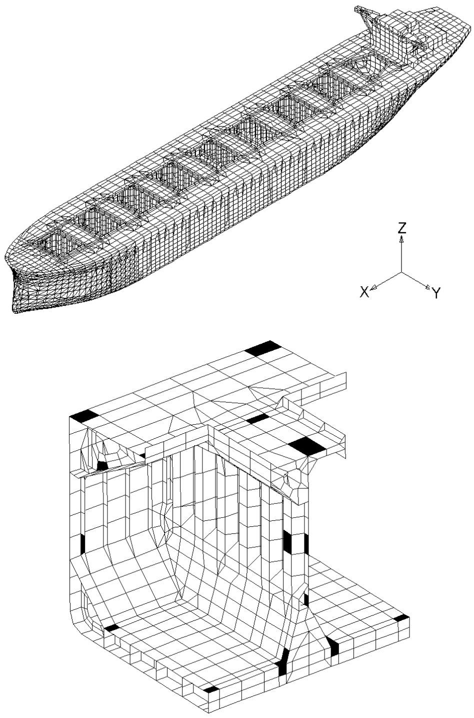

Fig.2 FE model and location of stress evaluation element (Bulk Carrier)

Figure 2 shows the FE model and the evaluation element position of the stress in the bulk career. All cargo holds were examined though Figure 2 has been partially taken out to show the location clearly. The number of all evaluation elements is about 150 elements. Next, ship motion, external wave load and internal load due to cargoe motion in waves were analyzed by the strip method. Theses

loads were applied to this ship model and the stress response function at major locations of structural members as a function of wave period and wave direction was analysed.
A short-term response was calculated using ISSC-1964 spectrum as the wave spectrum and the squred cosine wave directional distribution.

Short-term distribution of the stress response calculated thus was arranged and the wave period and wave direction where a standard deviation value which was the parameter indicating the severity of the stress response in irregular waves showed large response was examined. As an example, response of stress in longitudinal direction was shown in Fig.3
It has been understood that the stress response in the longitudinal direction concentrates regardless of member's position such as midship part, fore part and aft part, at the wave period for some specific wave direction(for wave direction 180 ° and wave period 12sec and for 0 ° , wave period 11sec), and becomes severe as a result. And it turned out that these wave conditions were coresponding to the condition where response of the vertical hull girder bending moment become the maximum.

It has been similarly understood that number of the waves condition related to the severity on strength is limited for the stress in

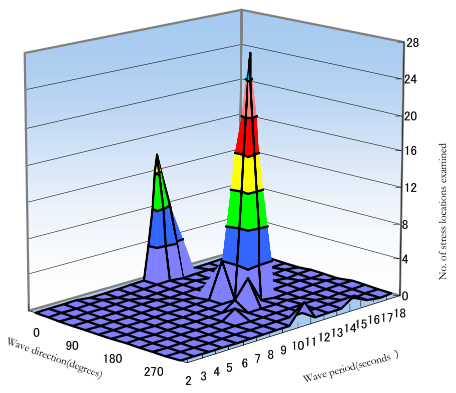

Fig.3 Dominant sea condition having the greatest impact on the structural response (Stress in longitudinal direction, Bulk carrier))

transverse direction and the shearing stress, etc.

These investigations show that the strength evaluation under a complex ocean wave environment can be done by evaluating a specific load condition corresponding to the type and the structural configuration of the ship without doing the huge analysis done so far.

3) Ocean waves in operational environment

When estimating the wave loads acting on a ship, it is first necessary to estimate the wave conditions being encountered by the ship accurately. This consists of conducting numerous studies into the height and period of waves occurring at sea and compiling statistical data on waves. At the same time, however, the master of most commercial ships selects the route of the ship based on forecasts about the weather along the course and his or her experience regarding the route up to that time. Consequently, the wave conditions actually encountered by the ship along its route may be considerably different from the statistically defined wave conditions occurring in the natural environment. Hence, in order to estimate the wave conditions that an average ship actually encounters and that are necessary when determining design loads, we conducted a study into the influence of maneuvering and ship operations under various wave conditions on ship response(see Fig.4).

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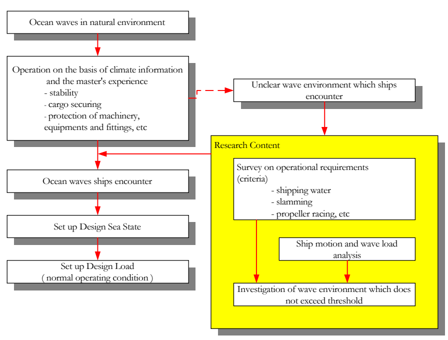


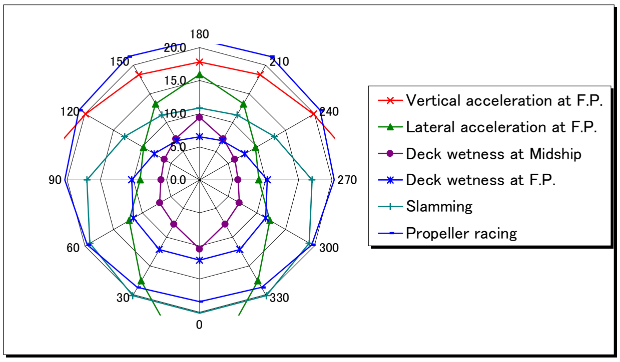
Fig.4 Design loads and normal wave environment encountered by ships

Although a ship is operated from the perspectives of stability, securing of cargo and protection of machinery, equipment and outfitting, the criteria for judging ship operations depend to a large extent on the knowledge and experience of the master and the operator. The operation limits and their occurrence probability are indicated in the paper by Kitasawa [1] and documents equivalent to the Operation Manual publised by Mercantile Marine Institute of Japan[2] and Japanese Captains' Association[3] and these documents are evidently serving as references for operations. Consequently, the short-term sea conditions that are actually encountered by ships during sound operations, which are the pre-requisites of classification societies since the past, that is, the worst sea conditions from the normal conditions, can be estimated from these reference documents on ship operations. In other words, the worst short-term sea conditions encountered actually by ships are likely to be different from the worst short-term sea conditions that can occur in the realm of nature. To define loads as practical design loads, the actual status of performance and operation of the ship need to be studied, and the short-term sea conditions that are likely to be actually encountered by a ship need to be clearly defined.

Based on the perspectives mentioned above, the threshold values of parameters that become criteria for operations of a typical ship such as deck wetness, exposure of bottom, propeller racing, and acceleration in the vertical and lateral directions were assumed as shown in Fig.5. The significant wave heights that occur due to these parameters were analysed, and the maximum significant wave heights considering the effects of operations of the ship to avoid rough seas were estimated.

Fig. 5 shows an example of the results. This figure shows the superimposition of significant wave heights that generate the threshold values of each operation parameter in the full-load condition of a bulk carrier. From this figure, the significant wave height considering the effects of operations to avoid rough seas can be estimated for each angle of encounter to waves from the range of operation in the full-load condition of the ship.

Factor	Threshold	
	Critical value	Probability
Vertical acceleration at Midship	0.45g	10^{-3}
〃 at F.P.	0.8g	10^{-3}
Lateral acceleration	0.39g	10^{-3}
Deck wetness at Midship	Freeboard	10^{-1}
〃 at F.P.	Freeboard	10^{-1}
Slamming	Draft	10^{-2}
Propeller racing	D/3 exposed	10^{-1}



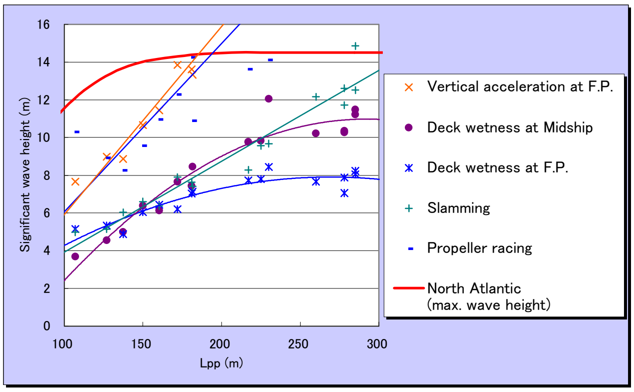


Fig. 5 Example of research into the operational environment of a sea

Based on the assumptions mentioned above, the inner most area in the figure can be estimated as the range of operations.

Furthermore, similar investigations were carried out for each loading condition of each ship. The estimated relationships between significant wave height that becomes maximum in the range of operations and the ship's length are shown in Fig.5. From these figures, it is seen that a correlation exists between the maximum significant wave height and the ship length. If ship length for a typical ship is known, it is possible to set the maximum significant wave height considering the effects of operations to avoid rough seas.

The range of operations has been estimated based on documents related to ship operations in this investigated example, but since such documents are being used as reference only, we have plans henceforth to examine the actual status of ship operations during rough weather, and to propose actual normal sea conditions.

3. Conclusion

The introduction presented above regarding is just a portion of the fruits of the extensive research being done with respect to the safety of hull structures for next-generation. It is hoped that the making the results of research opened to the public on a continuing basis will serve to stimulate further research into this important topic and thereby contribute to the promotion of ship's safety for the next generation.

References

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3) Japanese Captains' Association :Reference documents for operation(part 2), 1995